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Beam Waveguides in the Deep Space Network

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A beam waveguide is a mechanism for guiding electromagnetic radiation from one part of an antenna to another through a series of reflectors. Appropriate placement of reflectors on an antenna allows a "beam" to be guided "around the elevation axis" and/or "below the alidade." The beam waveguide permits placement of all electronics in a room on the alidade below the elevation axis, or below the alidade; feed horn covers to be protected from the weather; and feed electronics to be in spacious rooms rather than in crowded cones, and always level rather than tipping with change in elevation angle. These factors can lead to lower costs in new implementation such as Ka-band, better antenna performance at X-band, more efficient and stable performance of transmitters and receivers, and lower maintenance and operating costs. Studies are underway to determine methods for converting the major antennas of the Deep Space Network (DSN) to beam waveguide operation by 1995.

I. Introduction

A beam waveguide is an open waveguide where electromagnetic propagation does not depend on the boundary conditions of the walls. A beam waveguide system typically consists of an arrangement of reflectors that direct the beam from one location to another. The set of reflectors may be contained in large tubes, where minimal interaction occurs with the walls of the tubes.

Beam waveguide systems are used on antennas as a means of moving the focal point to a more convenient location. For example, on the Weilheim, Germany, 30-meter antenna shown in Figs. 1 and 2, the secondary focal point is located behind the main reflector, beyond the elevation bearing on the elevation axis. This has the primary advantage of allowing space for a large room that contains a dual frequency feed horn, two X-band masers, two S-band parametric amplifiers, receivers, and a transmitter; it also allows the electronics to remain level and keeps the feed horn cover dry despite rain.

Beam waveguide systems typically use curved reflectors or combinations of curved and flat reflectors. Flat reflectors simply redirect the beam; curved reflectors may refocus the beam in order to control beam divergence along the waveguide. Curved reflectors may be ellipsoidal, or paraboloidal; the shapes are sometimes modified to favor one frequency. Design considerations are addressed elsewhere (Ref. 1).

Beam waveguide systems can use a pair of reflectors along the elevation axis to bring the beam down to a feed electronics room on the alidade. Again, the reflectors can be flat or curved as desired. A second pair of reflectors can be used to advantage along the vertical axis to bring the beam to a pedestal room that is below the alidade (Ref. 2). Figure 3 shows these two configurations conceptually; Fig. 4 shows one of the three COMSAT antennas at Roaring Creek, Pennsylvania, where all feeds and electronics are within the stationary buildings on which the three 32-meter antennas are mounted. Figures 5 and 6 show the 64-meter deep space antenna at Usuda, Japan, with its three-story alidade building. The spacious interior of the Usuda alidade rooms provide a laboratory environment for transmitters, cryogenically cooled low-noise amplifiers, receivers, and much other equipment (see Fig. 7).

Beam waveguide systems can include many reflectors, including movable ones, in order to move the beam to any of several desirable locations. The 45-meter radio astronomy antenna at Nobeyama, Japan (Fig. 8), has the configuration of reflectors shown in Figs. 9 and 10. Note that the reflectors can be moved to redirect the beam. Vernier pointing of the antenna beam can be accomplished by movement of reflectors. Figures 11 and 12 show such a system for an aircraft-mounted 98-GHz radiometer, using a 43-cm X 63-cm scanning reflector (Ref. 3).

The DSN has used reflectors in a fashion similar to those in beam waveguides for over 10 years. As Fig. 13 shows, the dual-frequency (S-band and X-band) arrangement of dichroic plate and ellipsoidal reflector is like a beam waveguide system. However, these do not move the beam below the elevation axis and/or alidade. Hence, today DSN antennas contain their front-end electronics in cones and rooms that are crowded and that tip.

It is proposed to retrofit beam waveguide systems into existing DSN antennas, and to employ them on all new DSN antennas. These beam waveguides will be used to direct the beam below the elevation axis and/or the alidade, to provide vernier pointing where needed, to provide frequency sensitive beam splitting, and to redirect the beam with a movable reflector to allow the use of different or redundant sets of electronic equipment.

II. Performance Gains for the DSN

All advantages to the DSN will accrue because sophisticated electronic equipment now mounted above the elevation axis in DSN antennas without beam waveguides can be mounted in rooms below the elevation axis once beam waveguides are added. This means that the traditional single or multiple cones and transmitter rooms above the elevation axis can be eliminated.

Instead, all electronics will be housed in either a stationary feed room that does not tip or rotate (typical of COMSAT), or in a feed room that rotates, but does not tip (typical of Usuda and Nobeyama).

This has many implications for improved performance and operation. First, the crowded cones are replaced with spacious rooms in which new implementations can be installed without expensive rework. The electronics in the antenna are accessible all of the time – no need for downtime for maintenance on the electronics. Equipment can be moved in or out with no loss of antenna time, and without need for use of the antenna structure itself as a crane for moving heavy equipment.

Second, equipment can be simpler and easier to maintain within operating conditions. Cryogenic system gas lines will no longer traverse hundreds of feet from alidade platforms around the elevation axis. The lines will be short and fixed with no flexible sections. The long bundles of power and signal cables now running from alidade to above the elevation axis will largely disappear. Cables will be short and fixed. There will be no gas lines, water lines, or cables above the elevation axis except for electrical connections for the subreflector control and aircraft warning lights.

Transmitters will be cheaper to build and easier to maintain. For example, a non-tipping transmitter can use steam rather than water cooling – in fact, an increase in output power is possible without changing water flow rate because of increased efficiency of cooling through steam. Tolerances required for the proposed 34-GHz gyroklystron will be easier to obtain with a stationary design than with one designed to be tilted.

Cryogenic systems will also be cheaper and more reliable. Stationary units that store large volumes of liquid helium can be used to operate at temperatures below 4.2 K and extend mean time between failure for cryogenic systems from 2000 hours to 20,000 hours. Operating at temperatures near 1.5 K will reduce maser noise temperature by a factor of three, triple maser gain-bandwidth product, and allow operation of superconducting frequency standards in the front-end area equipment room on the antenna.

Frequency stability will be improved by eliminating flexing cables, controlling the environment for critical equipment and cable, and measuring and stabilizing or compensating in real time for beam waveguide length variations.

Finally, beam waveguides can provide increased antenna performance at X-band in the rain. This is because systems can be built so that feed horn covers and dichroic plates are not exposed to moisture. Light rain that should cause only 2 K additional noise at X-band can add 40 K due to water in the feed horn cover and dichroic plate with our current system.

The resulting signal-to-noise-ratio loss of 4 dB can be circumvented with beam waveguides. Figure 14 shows relative performance during rain at Weilheim, Germany, and as specified in the DSN at the 95% weather probability.

III. Converting the DSN

Tests conducted with a DSN S-band traveling wave maser on the 64-meter antenna in Usuda, Japan (Ref. 4) showed that the zenith system temperature was 1 K lower than that of a DSN 64-meter antenna, while at 30 degree and 10 degree elevation angles, the Japanese system temperature was 2.3 K and 3 K lower than the DSN's (Fig. 15). Usuda's lower noise temperature is thought to be due to less microwave scattering off the smaller quadripod support of the Usuda antenna.

There does not appear to be any major cost difference between an antenna with or without beam waveguide when building and equipping a new antenna. Probably the beam waveguide system has a lower cost. That is, the cost of the reflector system and large feed equipment room is more than offset by the reduced costs from not providing a cone, transmitter room, heavier quadripod, added counterweights, added cryogenic lines, added cabling, and the added cost of "tight" layout design in the crowded space above the elevation axis.

Thus, since neither lower performance nor higher cost should arise, it appears to be appropriate to build only beam waveguide designs for future DSN antennas. The new research and development antenna planned for the Venus site will not only utilize beam waveguides, but also be used to conduct extensive tests to answer questions about how the DSN can best utilize beam waveguide. Replacements for the old HA-DEC 34-meter antennas are expected to use beam waveguides. The remaining issue deals with conversion of the existing 64-/70-meter and 34-meter high efficiency (HEF) antennas.

Figure 16 shows one "conventional" beam waveguide configuration that is suitable for a 34-meter antenna (Ref. 5). For the HEF antennas, this would require rework of the elevation axis truss – that is, replacement of the horizontal beam with a "donut" support to allow the beam to be directed through to the center of the dish. This configuration is a possibility for the replacements for the old HA-DEC antennas. Figure 17 shows a "bypass" mode that transfers the beam "through" the reflector, but requires no structural changes in the elevation axis truss. This is a candidate for the HEF antenna since the horizontal support can be retained; both configurations are being considered for tests in the new research and development antenna at the Venus site.

Beam waveguide conversion for the 70-meter antennas remains uncertain. Initial surveys show that at least one approach can place the beam within the central column now used for the master equatorial pointing system. This could permit the pedestal area to be used for all transmitter and receiver equipment now housed above the elevation axis.

This assumes, however, that the 70-meter antennas will not use a master equatorial pointing system. Studies are now underway to find ways of converting to beam waveguide without loss of the master equatorial pointing system, and to find ways of pointing the 70-meter antenna without the master equatorial system.

IV. Concluding Remarks

The advantages of beam waveguides to DSN future implementation and operation are significant. Long range plans call for conversion of the DSN antennas during the 1990s. Replacement of the old HA-DEC 34-meter antennas is slated for the early 90s, conversion of the 70-meter antenna for the mid-90s, consistent with plans to add Ka-band reception; conversion of the 34-meter HEF antennas are less definite, but expected to occur in the late 90s.

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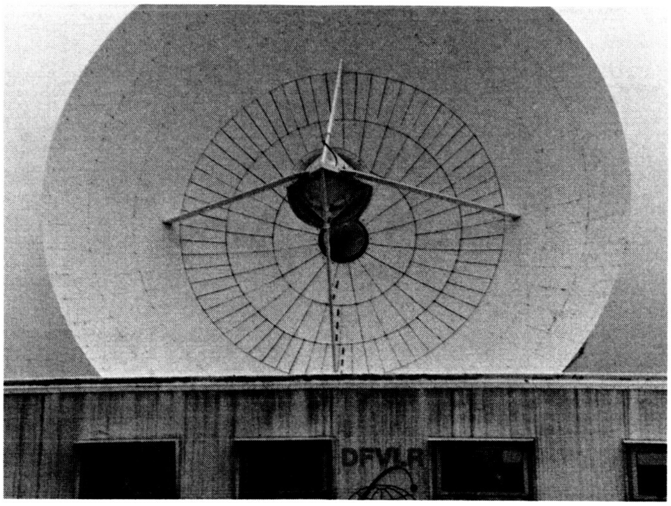

Fig. 1. Weilheim 30-m antenna viewed from front

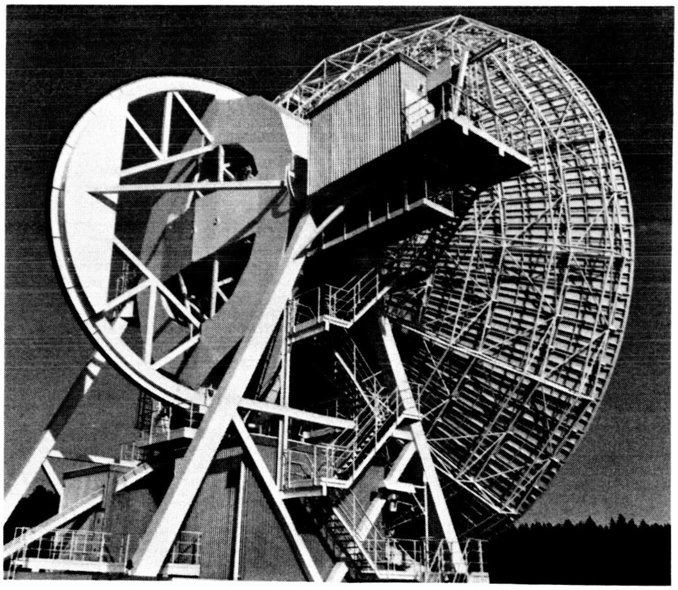

Fig. 2. Weilheim 30-m antenna viewed from rear

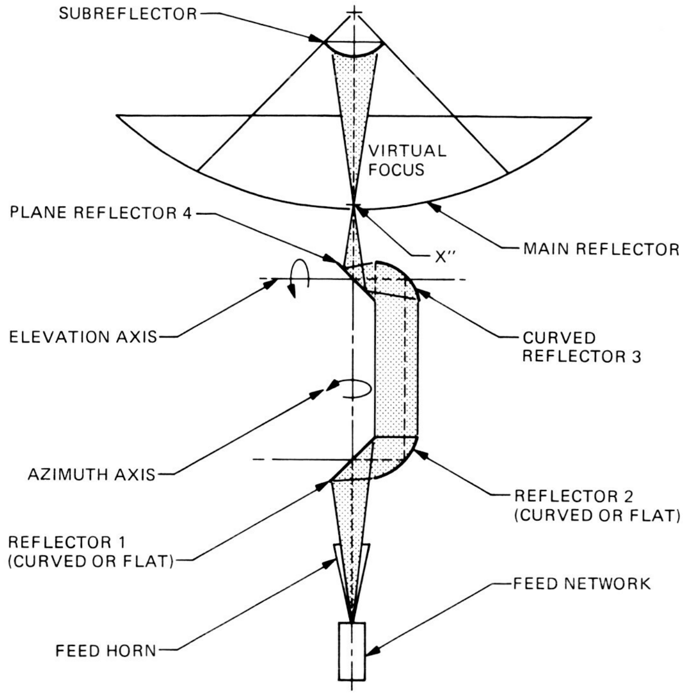

Fig. 3. Conceptual configuration of a beam waveguide

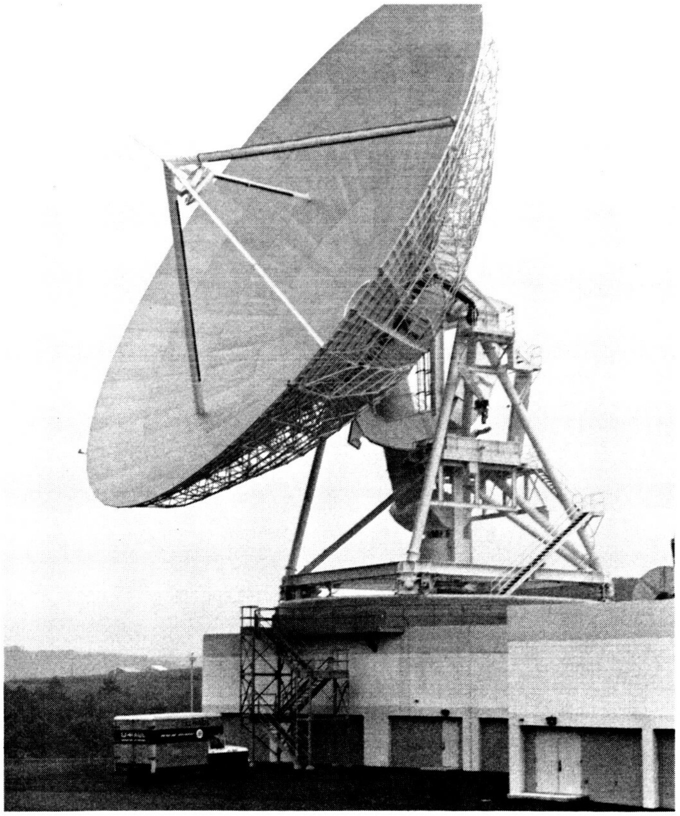

Fig. 4. 32-m COMSAT antenna at Roaring Creek, Pennsylvania

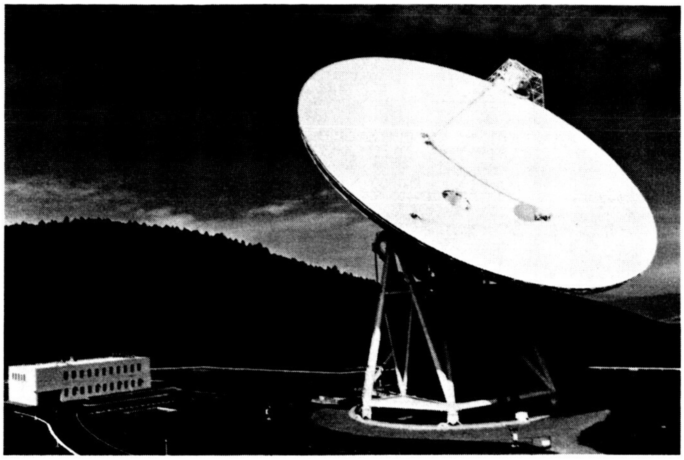

Fig. 5. Usuda 64-m antenna

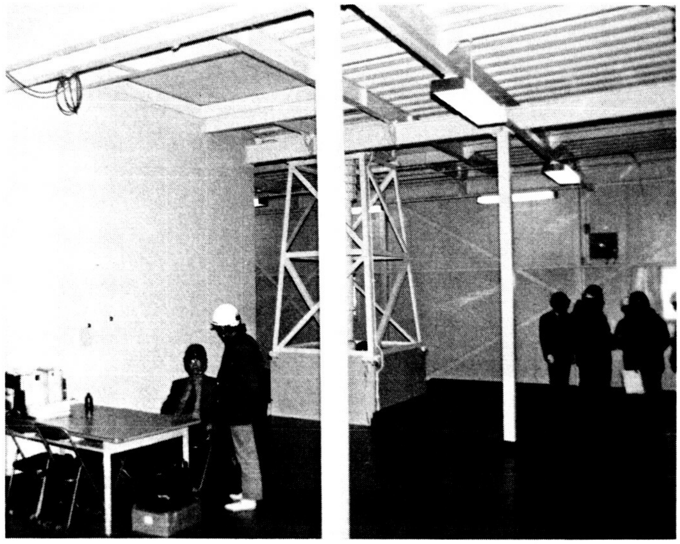

Fig. 7. Interior of Usuda alidade room

Fig. 6. Usuda 64-m antenna rear view

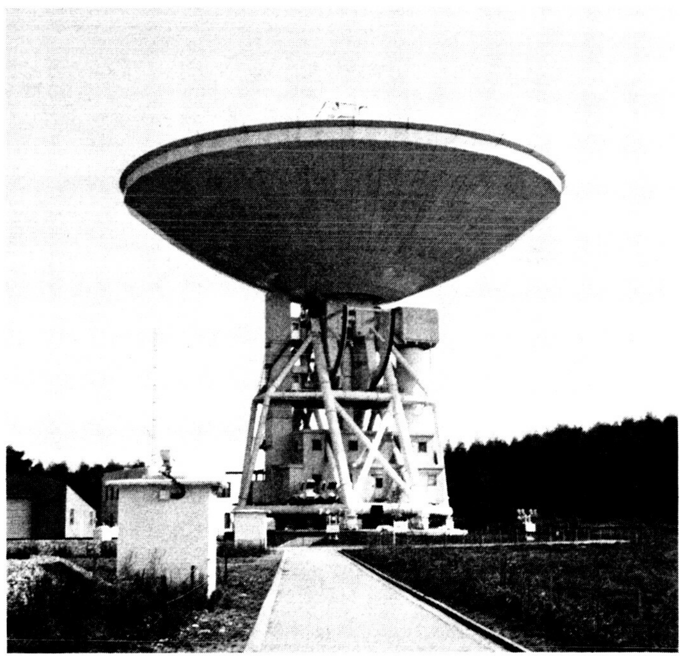

Fig. 8. 45-m radio astronomy antenna at Nobeyama, Japan

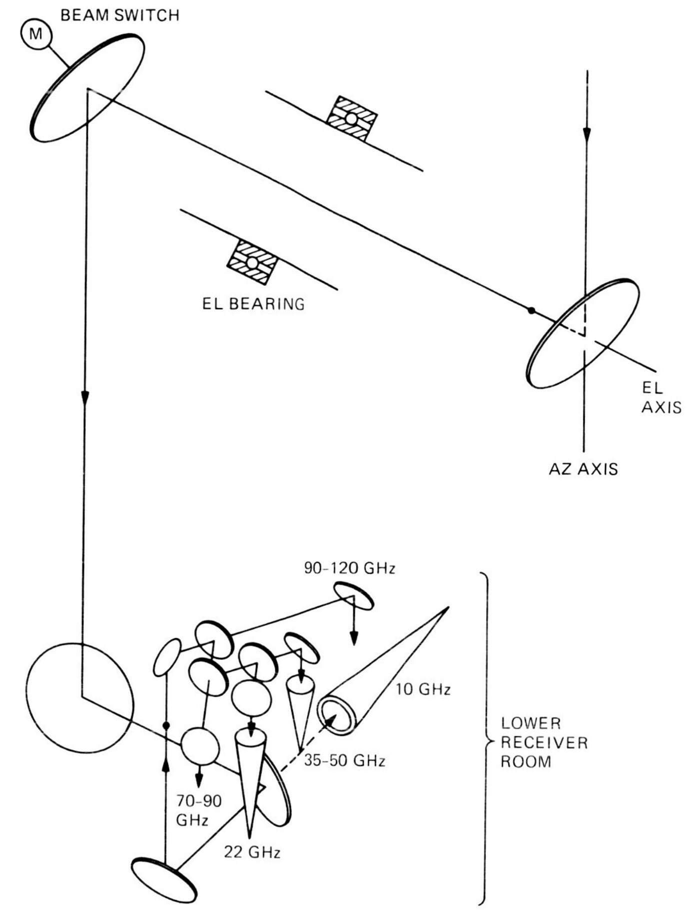

Fig. 9. Nobeyama 45-m antenna feed configuration

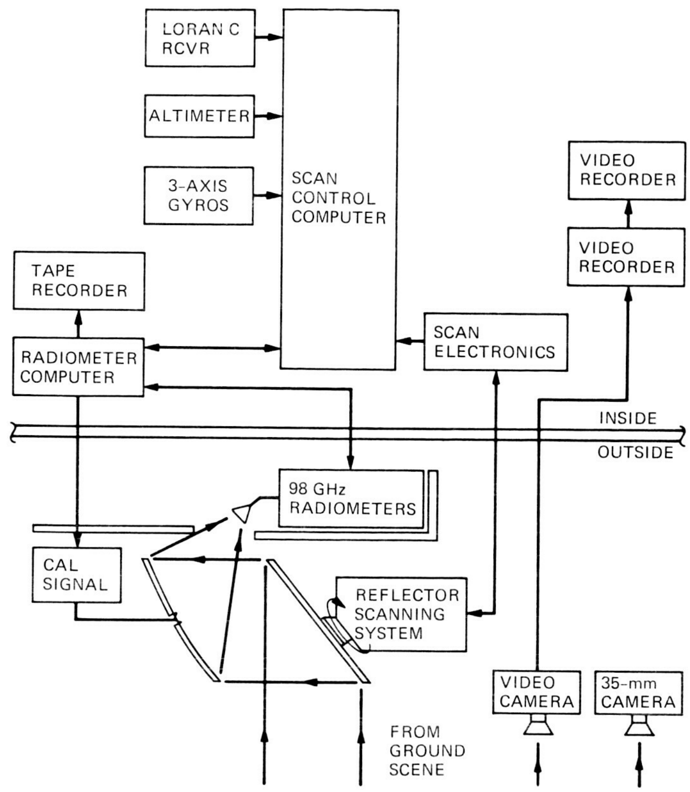

Fig. 11. Millimeter wave imaging sensing system

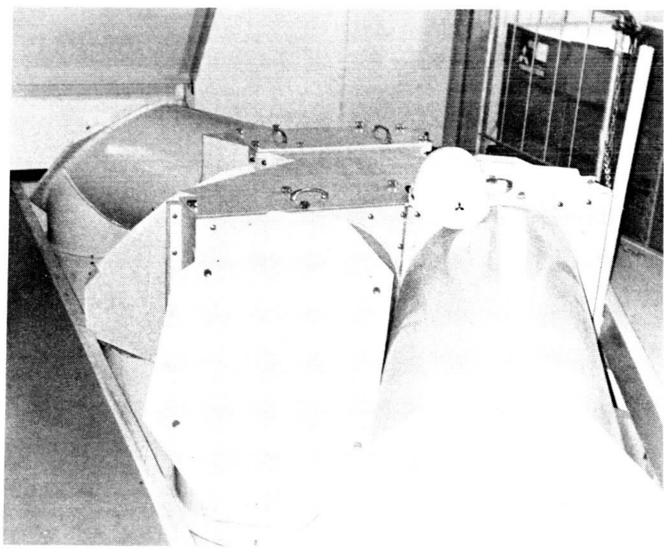

Fig. 10. Nobeyama 45-m antenna feed configuration and beam waveguide

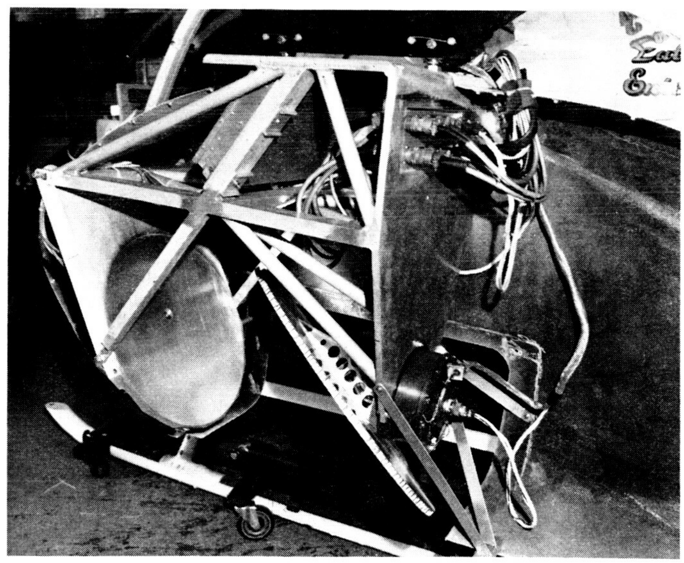

Fig. 12. Photograph of millimeter wave imaging sensing system antenna and scanning system

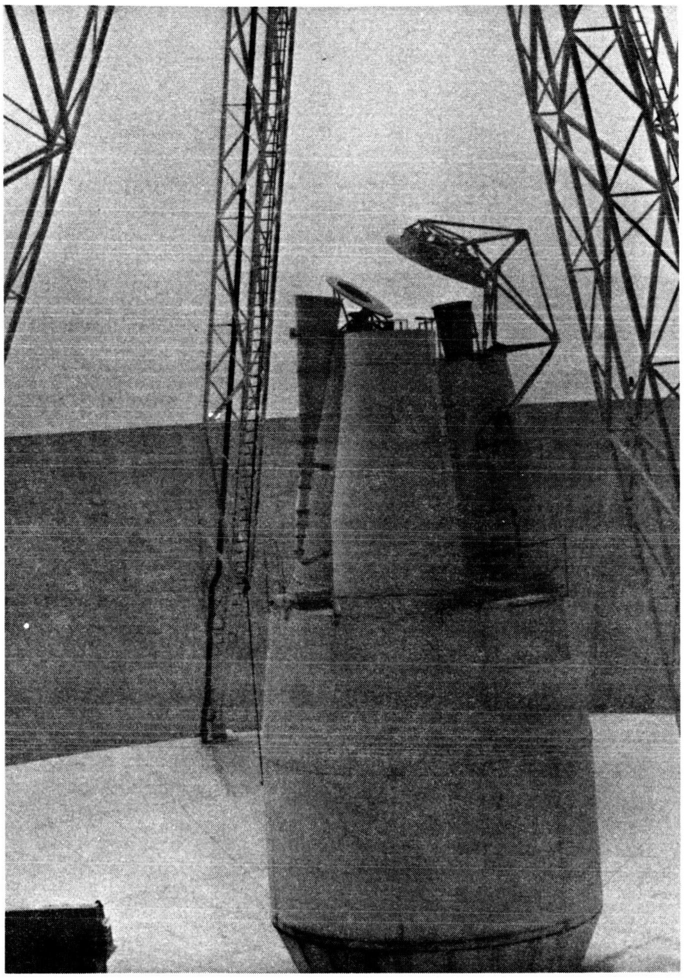

Fig. 13. DSS 14 64-m antenna feed system

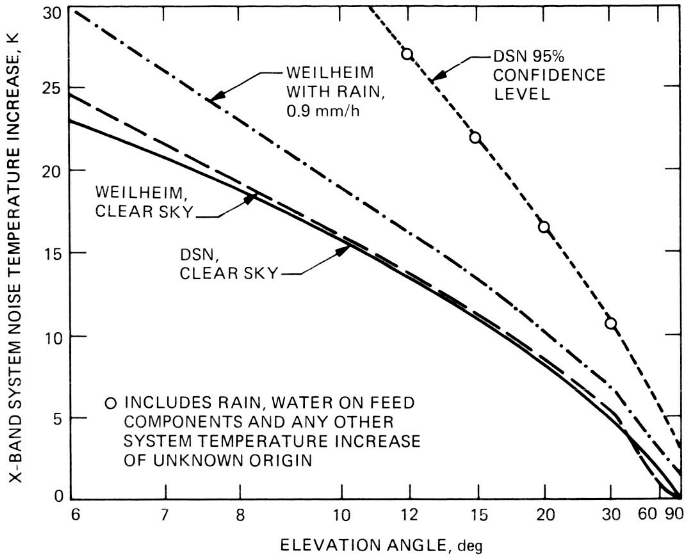

Fig. 14. X-band system temperature increase versus elevation angle

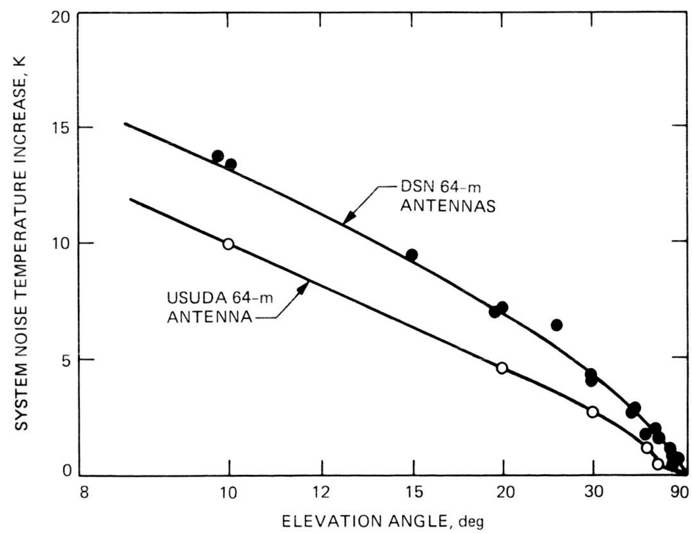

Fig. 15. S-band system temperature versus antenna elevation angle

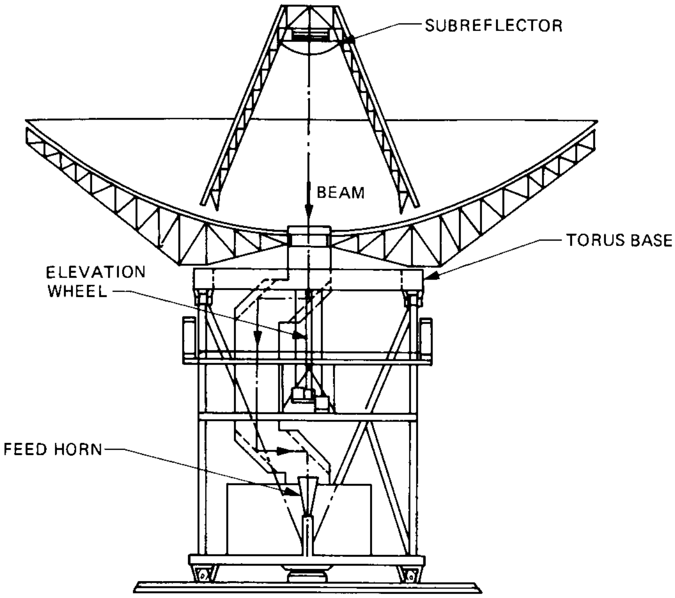

Fig. 16. Beam waveguide configuration for DSN 34-m HEF antenna

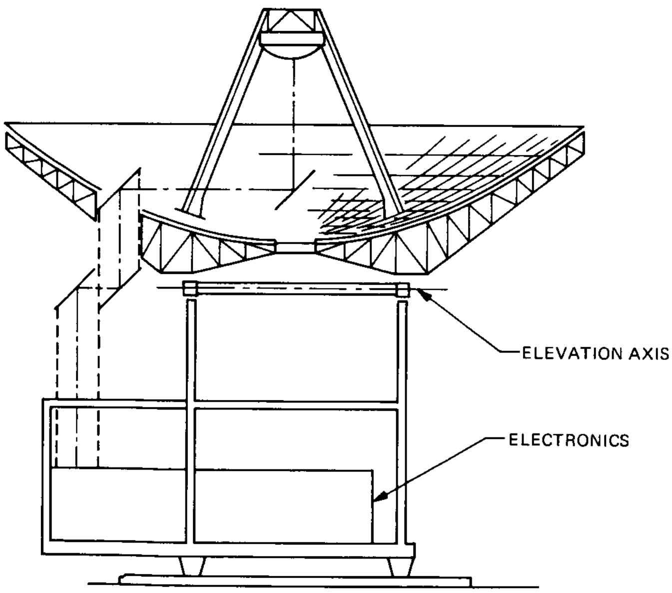

Fig. 17. Bypass-mode beam waveguide configuration for DSN 34-m HEF antenna